Margaret Hamilton (scientist)

Margaret Heafield Hamilton (born August 17, 1936)[2] is an American computer scientist, systems engineer, and business owner. She coined the term "software engineering". Hamilton was Director of the Software Engineering Division[3] of the MIT Instrumentation Laboratory, which developed on-board flight software for the Apollo space program.[4] In 1986, she founded Hamilton Technologies, Inc., in Cambridge, Massachusetts. The company was developed around the Universal Systems Language based on her paradigm of Development Before the Fact (DBTF) for systems and software design.[5]

Hamilton has published over 130 papers, proceedings, and reports about the 60 projects and six major programs in which she has been involved.

On November 22, 2016, Hamilton was awarded the Presidential Medal of Freedom by US President Barack Obama for her work leading the development of on-board flight software for NASA's Apollo Moon missions.[1][6]

Margaret Hamilton

Hamilton in 1995

Born	Margaret Heafield August 17, 1936 Paoli, Indiana, US
Education	Earlham College University of Michigan
Occupation	CEO of Hamilton Technologies, Inc. Computer scientist
Spouse(s)	James Cox Hamilton (div.)
Children	Lauren Hamilton
Relatives	James Cox Chambers (former son-in-law)
Awards	Presidential Medal of Freedom[1]

Contents

Early life and education

SAGE Project

NASA

Apollo 11

Businesses

Legacy

Awards

Personal life

Publications

See also

References

External links

Early life and education

Margaret Heafield was born in Paoli, Indiana, to Kenneth Heafield and Ruth Esther Heafield (née Partington).[7] After graduating from Hancock High School in 1954, she studied mathematics at the University of Michigan in 1955 and earned a BA in mathematics with a minor in philosophy from Earlham College in 1958.[8][9]

She briefly taught high school mathematics and French upon graduation, in order to support her husband while he worked on his undergraduate degree at Harvard University. She moved to Boston, Massachusetts, with the intention of doing graduate study in abstract mathematics at Brandeis University. She cites a female math professor as helping with her desire to pursue abstract mathematics. She had other inspirations outside the technological world, including her father (a philosopher and poet), and her grandfather (a school headmaster and Quaker Minister). She says these men inspired her to a minor in philosophy.[10]

In 1960 she took an interim position at MIT to develop software for predicting weather on the LGP-30 and the PDP-1 computers (at Marvin Minsky's Project MAC) for professor Edward Norton Lorenz in the meteorology department.[11][2][12] Hamilton wrote that at that time, computer science and software engineering were not yet disciplines; instead, programmers learned on the job with hands-on experience.[4]

SAGE Project

From 1961 to 1963, she worked on the Semi-Automatic Ground Environment (SAGE) Project at Lincoln Lab, where she was one of the programmers who wrote software for the first AN/FSQ-7 computer (the XD-1), to search for unfriendly aircraft; she also wrote software for the Air Force Cambridge Research Laboratories

The SAGE Project was an extension of Project Whirlwind, started by MIT, to create a computer system that could predict weather systems and track their movements through simulators; SAGE was soon developed for military use in anti-aircraft air defense from potential Soviet attacks during the Cold War. Hamilton said,

> What they used to do when you came into this organization as a beginner, was to assign you this program which nobody was able to ever figure out or get to run. When I was the beginner they gave it to me as well. And what had happened was it was tricky programming, and the person who wrote it took delight in the fact that all of his comments were in Greek and Latin. So I was assigned this program and I actually got it to work. It even printed out its answers in Latin and Greek. I was the first one to get it to work.[13]

It was her efforts on this project that made her a candidate for the position at NASA as the lead developer for Apollo flight software.

NASA

Hamilton then joined the Charles Stark Draper Laboratory at MIT, which at the time was working on the Apollo space mission. She eventually led a team credited with developing the software for Apollo and Skylab.[16] Hamilton's team was responsible for developing in-flight software,[17] which included algorithms designed by various senior scientists for the Apollo command module, lunar lander, and the subsequent Skylab.[4][18] Another part of her team designed and developed the systems software[19] which included the error detection and recovery software such as restarts and the Display Interface Routines (also known as the Priority Displays) which Hamilton designed and developed.[20] She worked to gain hands-on experience during a time when computer science courses were uncommon and software engineering courses did not exist.[4]

Hamilton in 1969, standing next to listings of the software she and her MIT team produced for the Apollo project.[14]

Her areas of expertise include systems design and software development, enterprise and process modelling, development paradigm, formal systems modeling languages, system-oriented objects for systems modelling and development, automated life-cycle environments, methods for maximizing software reliability and reuse, domain analysis, correctness by built-in language properties, open-architecture techniques for robust systems, full life-cycle automation, quality assurance, seamless integration, error detection and recovery techniques, man-machine interface systems, operating systems, end-to-end testing techniques, and life-cycle management techniques.[4][14]

Apollo 11

In one of the critical moments of the Apollo 11 mission, the Apollo Guidance Computer together with the on-board flight software averted an abort of the landing on the Moon. Three minutes before the Lunar lander reached the Moon's surface, several computer alarms were triggered. The computer was overloaded with interrupts caused by incorrectly phased power supplied to the lander's rendezvous radar.[21][22][5] The program alarms indicated "executive overflows", meaning the guidance computer could not complete

all of its tasks in real time and had to postpone some of them.[23] The asynchronous executive designed by J. Halcombe Laning[21][24] was used by Hamilton's team to develop asynchronous flight software:

Hamilton during her time as lead Apollo flight software designer.[15]

> Because of the flight software's system-software's error detection and recovery techniques that included its system-wide "kill and recompute" from a "safe place" restart approach to its snapshot and rollback techniques, the Display Interface Routines (AKA the priority displays) together with its man-in-the-loop capabilities were able to be created in order to have the capability to interrupt the astronauts' normal mission displays with priority displays of critical alarms in case of an emergency. This depended on our assigning a unique priority to every process in the software in order to ensure that all of its events would take place in the correct order and at the right time relative to everything else that was going on.[25]

Hamilton's priority alarm displays interrupted the astronauts' normal displays to warn them that there was an emergency "giving the astronauts a go/no go decision (to land or not to land)".[26] Jack Garman, a NASA computer engineer in mission control, recognized the meaning of the errors that were presented to the astronauts by the priority displays and shouted, "Go, go!" And on they went.[27] Dr. Paul Curto, senior technologist who nominated Hamilton for a NASA Space Act Award, called Hamilton's work "the foundation for ultra-reliable software design."[19]

Hamilton wrote of the incident,

> The computer (or rather the software in it) was smart enough to recognize that it was being asked to perform more tasks than it should be performing. It then sent out an alarm, which meant to the astronaut, *I'm overloaded with more tasks than I should be doing at this time and I'm going to keep only the more important tasks*; i.e., the ones needed for landing ... Actually, the computer was programmed to do more than recognize error conditions. A complete set of recovery programs was incorporated into the software. The software's action, in this case, was to eliminate lower priority tasks and re-establish the more important ones ... If the computer hadn't recognized this problem and taken recovery action, I doubt if Apollo 11 would have been the successful moon landing it was.[28]
>
> — Letter from Margaret H. Hamilton, Director of Apollo Flight Computer Programming MIT Draper Laboratory, Cambridge, Massachusetts[29], titled "Computer Got Loaded", published in *Datamation*, March 1, 1971

Businesses

From 1976 through 1984, Hamilton was the CEO of a company she co-founded called Higher Order Software (HOS) to further develop ideas about error prevention and fault tolerance emerging from her experience at MIT.[30] They created a product called USE.IT, based on the HOS methodology developed at MIT.[31][32][33] It was successfully used in numerous government projects.[34][35] One notable project was to formalize and implement the first computable IDEF, C-IDEF for the Air Force, based on HOS as its formal foundation.

One critical assessment contended that, apart from a few independent reviews, the HOS methodology generated little analysis except among consultants associated with the company.[36] That evaluation, conducted by a consultant for the United States Navy asserted that "the HOS literature tends to advertise their ideas and products more than making a contribution in substance to the field of Computer Science."[36] Edsgar Dijkstra described the USE.IT software as "mechanized aids for the application of obsolete techniques."[37] A detailed analysis of the HOS theory and AXES language was used by Harel to develop a derived language for a more modern form of structured programming derived from HOS called the And/Or programming language from the viewpoint of

and/or subgoals.[38] Referring to Dijkstra's classic work on structured programming, Harel states: "As will become clear, the "layers" in which the program is arranged, these being in the heart of the idea of structured programming, correspond to the levels of the tree." Harel goes on to show at that time how HOS and his derived And/Or programming language relates to mathematical logic, game theory and artificial intelligence. Others have used HOS to formalize the semantics of linguistic quantifiers.[39] and to formalize the design of reliable real-time embedded systems[40]

Hamilton left the company, HOS, in 1985. In March 1986, she became the founder and CEO of Hamilton Technologies, Inc. in Cambridge, Massachusetts. The company was developed around the Universal Systems Language (USL) and its associated automated environment, the 001 Tool Suite, based on her paradigm of Development Before The Fact (DBTF) for systems design and software development.[5][41][42][43]

Legacy

Along with Anthony Oettinger or Barry Boehm, Margaret H. Hamilton is one of the people credited with naming the discipline of "software engineering".[44][45] According to Hamilton:

Official photo for NASA, 1989

> During this time at MIT, she wanted to give their software "legitimacy", just like with other engineering disciplines, so that it (and those building it) would be given its due respect; and, as a result she made up the term "software engineering" to distinguish it from other kinds of engineering.[46]

Hamilton details how she came about to make up the term 'software engineering':

> When I first came up with the term, no one had heard of it before, at least in our world. It was an ongoing joke for a long time. They liked to kid me about my radical ideas. It was a memorable day when one of the most respected hardware gurus explained to everyone in a meeting that he agreed with me that the process of building software should also be considered an engineering discipline, just like with hardware. Not because of his acceptance of the new 'term' per se, but because we had earned his and the acceptance of the others in the room as being in an engineering field in its own right.[25]

When Hamilton started using the term "software engineering",[47][48][49] software development was not taken seriously compared to other engineering,[50] nor was it regarded as a science. She began to use the term "software engineering" during the early Apollo missions. Over time the term "software engineering" has gained the same respect as any other technical discipline.[51][44] The IEEE Software September/October 2018 issue celebrates the 50th anniversary of software engineering.[52] Hamilton talks about "Errors" and how they influenced her work related to software engineering and how her language, USL, could be used to prevent the majority of "Errors" in a system.[53] "At MIT she assisted in the creation of the core principles in computer programming as she worked with her colleagues in writing code for the world's first portable computer".[54] Hamilton's innovations go beyond the feats of playing an important role in getting humans to the moon. "She, along with that other early programming pioneer, CoBOL inventor Grace Hopper, also deserve tremendous credit for helping to open the door for more women to enter and succeed in STEM fields like software."[55][56]

Awards

- In 1986, she received the Augusta Ada Lovelace Award by the Association for Women in Computing.[8] This award is given to individuals who have excelled in either (or both) of two areas: 1. Outstanding scientific and technical achievement and 2. Extraordinary service to the computing community through their accomplishments and contributions on behalf of women in computing.[57]

- In 2003, she was given the NASA Exceptional Space Act Award for scientific and technical contributions. The award included $37,200, the largest amount awarded to any individual in NASA's history.[19][58][59]
- In 2009, she received the Outstanding Alumni Award by Earlham College.[8]
- In 2016, she received the Presidential Medal of Freedom from Barack Obama, the highest civilian honor in the United States.[60][61]
- On April 28, 2017, she received the Computer History Museum Fellow Award, which honors exceptional men and women whose computing ideas have changed the world.[3][62]
- In 2017, a "Women of NASA" LEGO set went on sale featuring (among other things) mini-figurines of Hamilton, Mae Jemison, Sally Ride, and Nancy Grace Roman.[63]
- In 2018, she was invested *honoris causa* by the Polytechnic University of Catalonia.[64]

Honoris Causa ceremony of Margaret Hamilton

Personal life

Margaret met her husband, James Cox Hamilton, while at Earlham College, where she was the homecoming queen and he the class president.[65] They married in the late 1950s after Hamilton earned her bachelor's degree.[65] James Hamilton became a lawyer, and also served on the board of the American Civil Liberties Union for many years, taking on *pro bono* cases.[65]

They had a daughter, Lauren, and two grandsons. During the weekends, Lauren often accompanied her mother to the lab, where she napped on the office floor while Margaret programmed routines that would ultimately be added to the Apollo's command module computer.[54] Margaret and James eventually divorced.[65]

Lauren married billionaire Cox heir James Cox Chambers on October 9, 1982.[66][67] They have a son, James Cox "Jim" Chambers Jr.[68][69] The two later divorced and Lauren married Richard David Selesnick, with whom she has a son, Mac.[70]

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See also

- List of pioneers in computer science

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External links

- MIT News
- Margaret Hamilton Video produced by *Makers: Women Who Make America*

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